Influencing incentives for precision agricultural technologies within European arable farming systems

Barnes, AP; Soto, I; Eory, V; Beck, B; Balafoutis, AT; Sanchez, B; Vangeyte, J; Fountas, S; van der Wal, T; Gomez-Barbero, M

Published in:
Environmental Science and Policy

DOI:
10.1016/j.envsci.2018.12.014

Print publication: 01/03/2019

Document Version
Publisher's PDF, also known as Version of record

Environmental Science and Policy 93 (2019) 66–74

Contents lists available at ScienceDirect

Environmental Science and Policy

journal homepage: www.elsevier.com/locate/envsci

Influencing factors and incentives on the intention to adopt precision agricultural technologies within arable farming systems

Andrew Barnes*, Iria De Soto, Vera Eory, Bert Beck, Athanasios Balafoutis, Berta Sánchez, Jürgen Vangeyte, Spyros Fountas, Tamme van der Wal, Manuel Gómez-Barbero

SRUC, Edinburgh, EH9 3JG, United Kingdom

ARTICLE INFO

Keywords:
Precision agriculture
Zero inflated Poisson regression
Arable farming
Incentives

ABSTRACT

Precision agriculture technologies (PATs) offer an approach to arable systems which both enhance productivity and minimise environmental harm. Despite expected economic gains uptake by farmers has been low. This paper explores the intended adoption of PATs through a survey of 971 farmers growing wheat, potato and cotton in five European countries. We apply a count data modelling framework to accommodate the inherent structural differences between the current adopters and non-adopters of PATs. This is augmented by qualitative analysis of the main thematic reasons for intended uptake. Results indicate non-adopters have more belief in their knowledge of field topology and are generally older than current adopters. Those non-adopters intending to adopt PATs in the future are more favourable to a wider range of incentives than current adopters. Attitudinal differences towards the economic certainty of investment and payback periods also emerge. The results indicate that a gradient of adoption is occurring within European arable farming systems which may lead to inequalities in technology access. Recognition of these differences at policy level could lead to cost-effective interventions which maximise uptake, generate returns to candidate farmers and meet policy desires for sustainable agricultural production in the future.

1. Introduction

Precision agricultural technologies (PATs) are a set of technologies aimed at the management of spatial and temporal variability. Optimal operation of PATs could potentially increase on-farm profitability, optimize yield and quality, reduce inputs and minimise environmental impacts (Godwin et al., 2003; Robertson et al., 2007, 2009; Silva et al., 2011; Aubert et al., 2012; Zhang and Kovacs, 2012; van der Wal et al., 2017; Smith et al., 2013; Eory et al., 2015; Schimmelpfennig, 2016). Under the constraint of limited land for agricultural production in the future (Beddington et al., 2012; Tilman et al., 2011), a range of policy documents support the uptake of PATs (Crookston, 2006; Zarco-Tejada et al., 2014; Schrijver et al., 2016). These documents infer that precision agricultural technologies are a key pathway for the future of commercial agriculture and support the sustainable intensification of agricultural systems (Gebbers and Adamchuck, 2010; Telabpour et al., 2015).

Farmers are beginning to embrace these technologies and a dialogue is maturing towards the opportunities for both harvesting significant data from sensor technology and for allied services offering interpretation of these data (Kerry et al., 2017; Sylvester-Bradley et al., 2017). Thus, PATs pose a potential disruption in demand for, and the skills of, farm management and labour (Schimmelpfennig, 2016) which may also affect the identity of the farmer from one of a land manager to farm technician (Tsouvalis et al., 2000). Accordingly, a growing wealth of research has examined the behavioural and structural characteristics of PAT-adopting farmers. Barriers relate to prohibitive costs of these technologies (Fernandez-Cornejo et al., 2001; Lawson et al., 2011; Cullen et al., 2013; Faber and Hoppe, 2013; Schimmelpfennig, 2016), and also the uncertainty of outcomes limiting the ability to adequately identify the return on investment of different technologies (Robertson et al., 2007; Montalvo, 2008). A number of studies have also found low levels of trust in the technology which negatively affects uptake (Bogdanski, 2012; Eidt et al., 2012; Busse et al., 2014).

The institutional context and in particular, the incentive structure for PATs have been under-explored in the literature on PAT adoption. The uncertainties found within the farming community towards PATs, compared to the potential societal gains from their adoption, challenges policy makers to design interventions which encourage their uptake. The purpose of this paper is to address these gaps by examining a range

* Corresponding author.
E-mail address: andrew.barnes@sruc.ac.uk (A. Barnes).

https://doi.org/10.1016/j.envsci.2018.12.014
Received 23 May 2018; Received in revised form 11 September 2018; Accepted 9 December 2018

of incentives that may influence the intention to adopt PATs. We explore this through a large cross-country survey of technology intentions within European arable farmers. Adoption of PATs within Europe is diverse across regions, with some countries typified by more intensive cropping activities. However, uptake in the European Union (EU) is lower compared to US or Australian systems (Barnes et al., 2019).

2. Methodology

2.1. Data collection

A survey was conducted between August 2016 and February 2017 across five European countries (i.e., UK, Germany, the Netherlands, Belgium and Greece). These countries were chosen to represent a diversity of different structural factors (e.g., in terms of farm size and intensity of production) and adoption rates. The sample was targeted at farmers and farm managers that were cultivating wheat, the crop most widely cultivated in Europe (Eurostat, 2015) and/or potatoes, a high value crop, with a high economic output per ha per year in the 2015/2016 cropping season. In Greece, cotton farmers were surveyed as a replacement for potatoes, because cotton is extensively grown throughout the country and PATs are mainly used in cotton production (Markinos et al., 2003; Gemtos et al., 2004, 2006; Balafoutis et al., 2017b).

Farmers were selected across equal strata based on their level of either non-adoption, or adoption of PATs. This approach was employed because of the lack of representative databases on PAT uptake within the EU region. Farmers were contacted through trade fairs, machine dealers, agricultural databases and personal contacts. They were selected on the basis of current non-adoption and current adoption of PATs. Once selected, farmers were interviewed mostly face to face, with a small number interviewed by telephone due to availability. Completed responses were estimated against Eurostat size and income data with each of the five countries and found to representative across these variables.

Farmers were presented with a suite of 8 common technologies which are currently available to farmers. These are shown in Table 1 in terms of what we refer to as threshold technologies, namely technologies that are required before further adoption of variable rate technologies can be achieved (Schimmelpfennig and Ebel, 2016; Balafoutis et al., 2017a,b). This latter set of technologies are identified as 'contingent', namely farmers can only adopt these discrete technologies if they intend to adopt or have currently adopted a threshold technology first[1].

As the focus of this paper is on farmer intentions to adopt, the count data were assembled to reflect a farmer's status with respect to the threshold technologies and their intended status with respect to contingent technologies. Specifically, non-adopters were defined as farmers with no current or future intention to adopt threshold technologies (0) or those who intend to or currently adopt threshold technologies (1). Then the number of contingent technologies were summed for each individual. Fig. 1, shows the counts following these rules for all farmers within the sample.

2.2. Modelling approach

A count regression modelling approach was applied as the technologies represent count outcomes for the individual farms (Isgin et al., 2008; Paxton et al., 2011; Castle et al., 2016). Within the suite of poisson models the zero inflated count model regression structure allows non-adopters to be considered through a different data generation process to the current adopters. The approach accommodates two latent groups, namely those who are always non-adopters (i.e. current adoption and future adoption intentions are null, referred to as 'always 0') because of structural barriers, and those which are current non-adopters but are able to adopt in the future, referred to as 'not always 0'. The predicted count outcome (Y_i), with z_i as a vector of explanatory variables for the 'always 0' group ($y_i = 0$) outcomes and x_i a vector of explanatory variables for the 'not always 0' group ($y_i > 0$) can be written as:

$$\Pr(Y_i = y_i x_i,\ z_i) = \begin{cases} \psi_i + (1-\psi_i)e^{-\mu_i}\, if\ y_i = 0 \\ (1-\psi_i)\,\frac{e^{-\mu_i}\mu_i{}^{y_i}}{y_i\,!}\, if\ y_i > 0 \end{cases}$$

where (ψ) is the probability of the logistic distribution. The zero inflated regression has two parts. A count model, which is applied to those adopting the technology, explains the factors influencing the intention to adopt the PATs, and a binary model, which is applied to non-adopters (n = 249), explains the threshold between non-adoption and intention to adopt PATs.

Table 1
List of precision agricultural technologies presented within the survey.

Threshold Technologies	Contingent Technologies
Machine Guidance (+/−2 cm accuracy)	Variable Rate technology for nitrogen application
Machine Guidance (+/−40 cm accuracy)	Variable rate irrigation
Controlled traffic farming	Variable rate pesticide application
	Variable rate seeding/planting
	Precision physical weeding

2.3. Explanatory variables

Socio-economic and structural variables are fairly common within the PAT adoption literature with studies finding that size and financial ability, through higher incomes, drives uptake (Fernandez-Cornejo et al., 2001; Olsen and Elisabeth, 2003; Griffin and Lowenberg-DeBoer, 2005; Robertson et al., 2012). We accommodate various dimensions of these structural variables (Table 2).

The statements identifying potential incentives for more intended adoption were developed initially between the researchers and the European Union Joint Research Centre policy team. These were then refined after discussion with a small number of industry representatives and from piloting the survey within each region. These statements covered financial incentives, e.g. "a 10% reduction in the present cost of the technology"; government interventions, e.g. "*directed subsidy support for uptake of PATs", "more stringent laws on pesticide and nitrogen application*"; informational incentives, e.g. "*improving technology to provide working maps based on soil maps*", and training support incentives "*more technical support from sales people*". These incentives were presented against a three point scale, from the incentive having no effect on uptake, a probable effect on uptake and a definite effect on uptake.

Very few studies explicitly explore attitudes towards uptake of PATs, aside from the farmer's lack of trust in the technology (Montalvo, 2008). The statement "*Investing in precision agriculture has too long a payback for the business*" reflected the financial constraints to adoption and *"I am too uncertain of the effects of PAT to invest in it*" to identify farmer confidence in the technology. Moreover, it may be that size of farm is only a perceived barrier rather than a physical barrier to uptake (Fernandez-Cornejo et al., 2001). Therefore we included the attitudinal question "*My farm is too small to invest in PAT*". Finally, a lack of compatibility between technology devices was identified by the statement "*My current machinery does not support the technology*" as this has been

[1] A full description of the technology provided to farmers is shown in Appendix A.

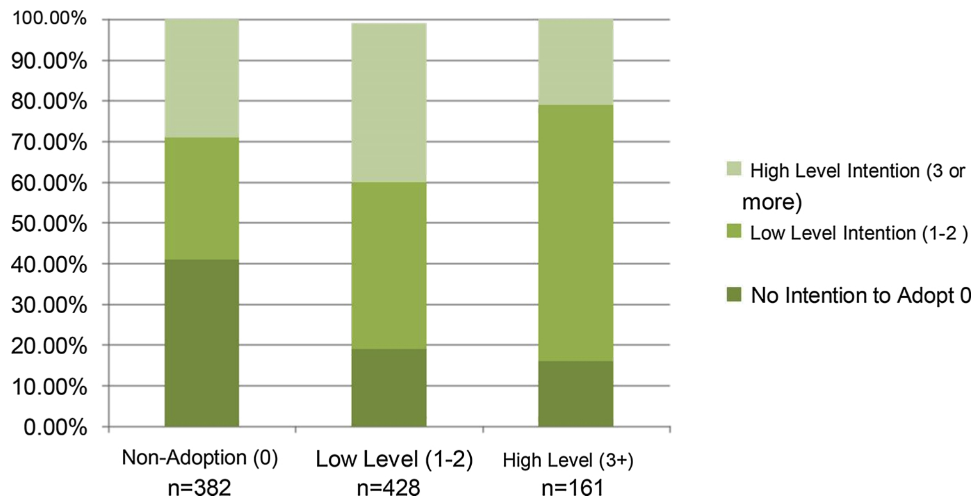

Fig. 1. Counts of PAT technologies, number of farms.

Table 2
Explanatory variables used, descriptive statistics.

Variable	Description	Mean	SD	Min	Max
AGE	Operator ages (categories)	0.8	0.6	0	2
EDUC	Agricultural educational attainment (binary)	3.7	2.1	1	7
SIZE	Total utilised agricultural area (ha)	223	481	2	5000
SPEC	Arable land to total utilised area to represent crop specialisation (ratio 0-1)	0.9	0.2	0	1
INC	Income of farm household in categories (euro)	3.5	2	1	7
LAB	Number of regular labour employed (number).	2.1	5.2	0	65
ISTAFF	'More support for training of my staff' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	0.6	0.8	0	2
IYIELD	'Confidence that yields would increase' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1.1	0.8	0	2
ICFCOST	'Confidence that my costs would reduce' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1.2	0.8	0	2
IFAM	'More support for training for myself and family' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	0.8	0.8	0	2
ISUPP	'More technical support from sales people' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	0.9	0.8	0	2
ISUB	'Directed subsidy support for uptake of PATs *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1.2	0.8	0	2
ITAX	'Financial support from tax breaks' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1.2	0.8	0	2
ICOST	'A 10% reduction in the present cost of the technology' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1.2	0.8	0	2
IRAD	'Government support for soil mapping, by providing ground penetrating radar or intensive soil sampling' *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	0.9	0.8	0	2
IMAP	'Improving technology to provide working maps based on soil maps'. *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1.1	0.8	0	2
IREG	'Stringent laws on pesticide and nitrogen application'. 3-point scale *3-point scale of no effect, probable effect on uptake, definite effect on uptake.*	1	0.8	0	2
ECONATT	*Investing in precision agriculture has too long a pay back for the business'.* 5-point Likert attitudinal scale.	0.3	1.1	−2	2
SIZEFARM	*My farm is too small to invest in PAT'.* 5-point Likert attitudinal scale	0.1	1.3	−2	2
MECHFIT	*My current machinery does not support the technology'.* 5-point Likert attitudinal scale.	−0.1	1.2	−2	2
TRAINLAB	My employed labour does not have the training. 5-point Likert attitudinal scale.	−0.3	1.0	−2	2
ADVIS	Advisors; 0: Not an influence; 1: Influence on adoption	0.6	0.5	0.0	1.0
OTHFARM	Other farmers; 0: Not an influence; 1: Influence on adoption	0.8	0.4	0.0	1.0
CONT	Contractors; 0: Not an influence; 1: Influence on adoption	0.5	0.5	0.0	1.0
REG	A set of dummy variables representing each country with Belgium as the reference value				

raised by a number of studies (e.g. Stafford, 2000). Respondents were given a 5-point Likert scale from strongly agree to strongly disagree with these statements.

2.4. Qualitative analysis of intended behaviour towards PAT adoption

In addition to the quantitative assessment, there were follow-up open questions which were asked of respondents who could volunteer further reasons for their responses around intended adoption. Qualitative responses were translated by the authors into English and then reviewed using thematic analysis to identify the common themes emerging from sub-strata of responses around intentions for adoption (Guest et al., 2012). These were grouped using categories of non-adoption and adoption with the aim of understanding thematic reasons for their intended behaviour towards PAT adoption.

3. Results

A likelihood ratio test found the ZIP favourable over the Zero-Inflated Negative Binomial (ZINB) (LR = *27.53* (*p = 0.000*)), and had a lower BIC value (zip = 3010.176, zinb = 3112.239). Collinearity between variables was assessed using Variance Inflation Factors (VIF) for the regressors and all variables were between 1.37–3.12 with a mean VIF of 2.30. This is well within the recommended parameters for low collinearity (Kutner et al., 2004). The regression fit was fairly good, with a Nagerleke R^2 of 0.43.

The results of the ZIP model are shown below Table 3, presented as raw coefficients (β), significance level (*sig.*) and odds ratios ($exp(\beta)$). We focus the discussion on odds ratios as these provide indications of the likelihood of factors which would lead to uptake of more precision agricultural technologies for the adopters or the likelihood of non-adoption of PATs in the non-adoption model.

Table 3
Zero-inflated Poisson regression coefficients (β) and odds ratios (*exp(β)*)[Φ].

	Adopters			Non-Adopters		
	β	*sig.*	*exp(β)*	β	*sig.*	*exp(β)*
Age (< 45)						
45-65	0.008		1.008	0.250	*	1.290
65+	0.112		1.118	1.560	*	4.740
EDUC	0.040	**	1.041	0.074		1.077
SIZE	0.000		1.000	−0.051	**	0.950
SPEC	−0.222		0.801	−1.239		0.290
INC	0.005		1.005	−0.410	*	0.664
LAB	0.005		1.005	−0.942	**	0.390
Incentives						
ISTAFF	0.087	*	1.091	3.027	*	20.643
IYIELD	0.025		1.025	−1.526		0.217
ICFCOST	−0.076		0.927	−0.967		0.380
IFAM	−0.002		0.998	−3.304	**	0.037
ISUPP	0.008		1.008	−3.736	*	0.024
ISUB	0.012		1.012	−1.861	**	0.155
ITAX	0.001		1.001	1.768	*	5.860
ICOST	0.065		1.067	−0.652		0.521
IRAD	0.036		1.036	−1.706	*	0.182
IMAP	0.057		1.059	−0.643		0.526
IREG	0.083	*	1.087	−0.035		0.966
Attitudes						
ECONATT	0.012		1.012	0.141	*	1.151
SIZEFARM	0.018		1.018	0.633	*	1.883
MECHFIT	0.028		1.028	0.781	*	2.184
TRAINLAB	−0.013		0.987	−0.379		0.685
ECONCERT	−0.052	*	0.949	−0.735		0.480
Influences on adoption						
ADVIS	0.121	*	1.128			
OTHFARM	0.059		1.061			
CONTRACT	−0.237		0.789			
Region (Belgium)						
GERMANY	−0.075		0.928	−4.27	*	0.01
GREECE	−0.567	***	0.567	0.69	***	1.99
NETHERLANDS	0.213	*	1.237	−0.818		0.441
UK	0.029		1.029	−2.089		0.124
N	971		LR chi2(30)			137.7***
Nagelkerke R^2	0.43		Log likelihood			1447

Reference class for dummy variables in brackets.
[Φ] p. * 0.05, ** 0.01,*** 0.001.

3.1. Intentions to adopt by current adopters

Education has a positive effect on the intention to increase the number of PATs. Respondents are more likely, by a factor of 1.04, to adopt more PATs than those without an agricultural education. Size and income indicators have no significant effect on intended adoption within the current adopters model. Accordingly whilst adoption may be contingent on size and income characteristics, it is a less prevalent characteristic for further adoption. This relates to the positive response found for training of staff for the technology. This is mostly reflective of the larger size of the current adopters compared to non-adopters, as this group would be expected to have more regular labour concerned with the day to day running of the arable enterprises.

For those intending to adopt more technologies, the incentive that will have an effect on adoption is more regulation on agrochemical application (IREG). This may indicate awareness that these technologies lead to reduced inputs, as it relates to environmental quality. Moreover, it may be linked to Government regulation seeking ways to increase N-use efficiency (Guillem and Barnes, 2013; Barnes et al., 2013). It may also be reflective of resistance found by some producers towards regulation, where technologies have been adopted which were considered appropriate for the farm and only further adoption will occur if farmers are obliged to, through more restrictive regulations (Barnes et al., 2013).

Of the attitudinal variables, only the statement '*I am too uncertain of the effects to invest in it*' proved significant with odds less than 1, i.e. more certainty of the outcome would lead to more uptake of PATs. This would seem to agree with a number of previous studies which found the higher levels of trust assigned to a technology leads to more PAT uptake (Bogdanski, 2012; Eidt et al., 2012; Montalvo, 2008).

In terms of influencing adoption of PATs, the use of advisors increases the odds of more PATs, whereas farmer-to-farmer interactions and contractors do not prove significant. This may reflect the knowledge gap, identified by Busse et al. (2014), in that advisors provide a supporting role for encouraging adoption. Moreover, Feder et al. (1985) identified both farmer extension and field demonstration as important factors in the diffusion of innovation. This may be required for current adopters to ensure that the PAT fits the farm's current technological structure. The role of farmer-to-farmer discussion is also a potential source of information (Rogers, 2003; Propokny et al., 2008), but this may not be applicable to PATs, as these technologies are technically advanced and have a high cost of implementation.

3.2. Intentions to adopt by current non-adopters

The non-adopter model shows the odds of the independent variables influencing the intention to not adopt PATs. A farmer over 65 has increased odds of intended non-adoption of PATs by a factor of 4.7. The PAT adoption literature tends to equate younger farmers with those more likely to adopt newer technologies (Lambert et al., 2015). The PATs available to these farmers are technically advanced and require a level of engagement and interaction to act upon the results. This engagement may appeal to younger farmers who are more exposed, as a generation, to information technology solutions, compared to the assurity towards the field's heterogeneity observed in older farmers.

Another common finding is related to size proxies and larger farms are more likely to adopt PATs (Fernandez-Cornejo et al., 2001; Castle et al., 2016; Schimmelpfennig, 2016). The odds ratios below 1 confirm this, i.e. large farms are less likely to be non-adopters compared to smaller farms. This is further confirmed by the significant attitudinal variable of perceptions towards the size of farm (SIZEFARM). This generates odds ratios over 1 and indicates that a farmer in strong agreement to this statement would tend towards non-adoption.

Size is normally coupled with an income measure (INC) which is also below 1 and leads to a general view that the larger farms with more household income are more likely to intend to adopt PATs than smaller farms with lower household incomes. This result also relates to the one attitudinal statement, namely '*Investing in precision agriculture has too long a payback for the business*' (ECONATT) which is significant. This is a negative statement reflecting economic confidence towards an expected rate of return and farmers who are in agreement would be more likely to remain non-adopters. A further significant attitude statement relates to a perception that the current machinery on the farm does not support the technology. There is also some compulsion to 'lock-in' or inhibit further adoption through the non-standardization of data formats and transfer protocols across manufacturers (Stafford, 2000). Consequently, this result seems to be reflective of the lack of complementarity between different manufacturer's technologies.

Finally, there is a difference between the effects of incentives on the non-adopters compared to the adopters. The incentives which would lead to producers being more likley to intend to adopt PATS are around government support "*Directed subsidy support for uptake of PATs*" (ISUB), and "*Government support for soil mapping, by providing ground penetrating radar or intensive soil sampling*" (IRAD) and training support "*More support for training for myself and family"* (IFAM), as well as *'More technical support from sales people'* (ISUPP). This is in contrast to a strong opinion that "*More support for training of my staff*" (ILAB) would contribute to producers being less likely to intend to adopt PATs. This may be due to returns to training costs of the family, which can be internalised into savings for a farming household, as they represent long-term

Table 4
Further reasons for non-adoption of PAT, percentage of responses and number of responses.

Non-Adopters	N = 160
High cost of technology	23%
Farm is too small	22%
Lack of information	19%
Low ROI	11%
Too old	9%
Self knowledge of the farm	5%
Farm land too scattered	3%
Farm biophysical constratints	3%
No capital replacement required	3%
Technology too complex	3%

Table 5
Further reasons for adoption of PAT for those with threshold technologies, percentage of responses and number of responses.

Threshold Adopters	N = 204
Cost reduction	29%
More accuracy/precision	22%
Ease of use	9%
Reduced agrochemical input	7%
Higher ROI	7%
More efficiency	6%
Reduced workload	6%
More labour efficiencies	4%
Increase yields	3%
Technical efficiency	3%

investments, compared to regular labour whose training allows them leverage to move to other farming businesses. In addition, "*Financial support from tax breaks"* (ITAX) would also contribute to less liklihood of intention to adopt PATs, as this is perhaps reflecting the smaller asset base of these farmers.

3.3. Qualitative analysis

To understand differing perceptions towards adoption and non-adoption qualitative responses were grouped into i) non-adopters, farmers with no technologies currently adopted or intention to be adopted, ii) threshold farmers, those farmers who only intend to adopt machine guidance or controlled traffic farming devices, iii) low level adopters, those farmers who intend to adopt less than 3 PATs, and iv) high level adopters, those farmers who intend to adopt 3 or more PATs. For these latter two classes we follow Miller *at al.* (2017) who identified intensive adopters as those with three or more bundles. The responses were coded into common fields and are shown below in terms of the frequency by which statements were given for each of these categories.

3.3.1. Non-adopters

For this group the main concerns were around farm physical constraints. Specifically they believed that PATs require larger fields to use these technologies and therefore did not consider their current farming structure appropriate for adoption (Table 4). They also highlighted no need for replacement of their machinery and this, in conjunction with the near retirement status of some farmers, shaped their views towards the technology. What also emerged from the group was a belief in their own knowledge of the fields and their ability to farm their fields adequately without technological aids, for example one German farmer stated:

> ‘I do not see the benefits, I can drive myself straight’ (Farmer DE884)

Moreover, a UK farmer stated

> ‘I'm not convinced that it's delivering reduced costs … Our combine is all laser guided off the header, having a machinery guidance means the only difference is it's using a satellite instead of the laser to guide it so I don't see the point.’ (Farmer UK550)

3.3.2. Threshold technology adopters

A common reason mentioned by this group was the need to reduce agro-chemical inputs, which is also reflected by statements focused on increasing efficiency and reducing costs (Table 5). Hence, whilst some of the response to adoption of PATs could be related to the requirement to engage in environmental behaviours (e.g. Siebert et al., 2006), this seems to be mostly related to profitability concerns, where environmental benefits are secondary for these farmers. Whilst return on investment (ROI) was raised, some farmers identified a scepticism towards an adequate economic return. For instance a farmer from the Netherlands stated:

Table 6
Further reasons for adoption of PATs for those with low level adoption technologies, percentage of responses and number of responses.

	N = 98
Cost reduction	23%
More accuracy/precision	14%
More efficiency	13%
Ease of use	7%
More comfort	7%
Higher ROI	6%
Identify as a progressive farmer	6%
Increase yields	4%
Reducing agrochemicals	4%
Reducing workload	4%

> “there is insufficient belief in return on investment” (Farmer NL99)

There was also awareness of how imprecision currently exists within the PATs available if input costs rise. A UK farmer stated:

> “as cost of chemicals and fertilizer increases more precision will be needed.” (Farmer UK 419).

3.3.3. Low level adopters

Statements promoted for adoption were the greater reduction in the cost of the technology (Table 6). This relates to the market structures for PATs and accessibility of these technologies within rural economies. Ultimately, access is driven by coverage of a small number, or in some cases only one, dealer. Moreover, the desire for more accuracy and precision was highlighted which may be contrasted to the observation of McBratney et al. (2005) that most assessments of PATs are at a single field scale and generally reflect experimental conditions. Given the heterogeneity of fields the scaling up of benefits are driven by uncertainties which will ultimately affect the payoff from investment (Lawson et al., 2011).

Related to this a number of farmers argued that adoption would be engendered by more than a 10% reduction in the cost of the technology. Cost is a common barrier found in previous studies of adoption and clearly links to wider findings of size being an inhibiting factor for adoption. The stated need for more information around the benefits can be considered in parallel to concerns around understanding the applicability of the PATs on the diversity of farming systems, and the needs for both a proven benefit and a higher return on investment to induce more PAT uptake. A Netherlands farmer vocalised the need for more applied information as:

> “thorough implementation research into the effect on yield; correct prescription maps based on field measurements” (Farmer N505)

In addition, farmers sought some assurity of non-biased research that could be provided by non-industry funded research. A Greek and

Table 7
Further reasons given for adoption of PATs for those with high level adoption technologies, percentage of responses and number of responses.

	N = 408
Cost reduction	22%
More accuracy/precision	20%
Ease of use	9%
More efficiency	7%
Higher ROI	7%
Reduced agrochemicals	7%
More labour efficiency	7%
Reduced workload	5%
Increase yields	4%
More comfort	4%

UK farmer stated:

"scientific proof of returns on investment" (Farmer GR128)
"proven independent testing" (Farmer UK618)

3.3.4. High level adoption

Cost issues were also prevalent within high level adopters as well as the desire for more accuracy, and ease of use (Table 7). Preferences for this group were identified as the need for more technology development and harmonisation between equipment manufacturers, which reflects their technology facing approach to farming:

"Better Internet in the rural area (data transfer, RTK[2] reference signals, prescription maps). I am using drone images." (Farmer NL2)
"mechanical sensor-driven techniques, if it works, we do not need the chemical" (Farmer GR971).
"Better communication between different software / management packages. Better substantiated task maps (prescription maps)" (Farmer NL424).

A small number of current high adopters identified their motive was driven by curiosity or they perceived themselves as progressive farmers. They felt PATs were simply part of an inevitable shift in the development of agricultural production and therefore they were required to adopt this technology:

'...we need to move with the times' (Farmer DE902)
'Progress and effectiveness, we must move with the times' (Farmer DE780)

Standardisation and improved product quality were also mentioned, specifically the desire to create some uniformity in production given the variance in soils and the ability to plough straighter lines. This would allow more standardisation in production and improved product quality:

'to try and even everything out, we have variable soil and with the applications we can even out harvest dates' (Farmer UK34)
'It was to even out variation across ground to make more uniformed crops, better targeting of problem areas.'(Farmer UK178)
'To try and even out yields across the fields.' (Farmer UK52)

This knowledge of spatial variability has been found to be a factor in driving adoption (Isgin et al., 2008; Khanna, 2001) as the reduction of input use is greater when low variability exists. Furthermore, this may allude to Burton (2004) observation around cultural capital/recognition within farming and that the presentation of uniformity is reflective of being seen as a 'good farmer'. This offers a further distinction between current and intended adoption within these arable farming systems.

4. Discussion

Precision agricultural technologies offer an attractive panacea for policy makers who express the desire for sustainable food production under future land and climatic pressures. Previous studies have mostly focused either on what drives adoption of PATs or the farm level cost impacts of adopting PATs. As far as we are aware no study has focused on the incentives that would encourage further adoption and this paper addresses this gap to inform this growing dialogue.

What emerges are differences dependent on the level of adoption choices of farmers. Effectively the decision to firstly adopt PATs can be influenced by a wider set of incentives than those currently adopting PATs. This infers different populations operating within agriculture. Barnes et al. (2011) argue that these populations dictate engagement strategies as they are driven by different perspectives that shape the framing of solutions to these distinct communities. Moreover, from a policy perspective engaging particular communities would influence the cost-effectiveness of interventions within the sector. Those non-adopters who have expressed no intention to adopt in the future tend to display a stronger belief in their own knowledge, a cynicism towards the technology, or a perception of structural constraints, in terms of land topography and size, which cannot be overcome by application of PATs. These are smaller farms with limited resources to invest. This leads to issues around equity and access to these technologies which, whilst small areas of land are managed, offer havens for maximising social returns as they are usually vulnerable household farms with diverse enterprises. This diversity in land quality will create a further barrier to uptake and inevitably leads to polarities and inequalities for the technological trajectories of farming communities (Chandra et al., 2017).

The issue of low income farmers raise fundamental questions over the role of the public sector in supporting uptake of PATs. Given ambitions within Europe to reduce reliance on agrochemical inputs there is an argument for intervention as this would promote the protection and maintenance of natural capital. Whilst there seems to be a desire to encourage uptake there is no direct regulatory push to adopt PATs in the EU. Moreover European agricultural policy has instruments, such as support for modernization of tractors, which could be more aligned with support for PATs.

Schrijver et al. (2016) show the diffuse nature of the policy landscape needed to encourage uptake of PATs. These involve telecommunications regulations, data access legislation and data transfer protocols. Developing cohesion between technologies, policies and infrastructure would seem a particularly challenging, yet pertinent, problem for engendering a significant uplift in PAT adoption. More indirect drivers, through tightening of the EU Nitrates Directive (Monteny, 2001), may encourage some farmers to use agronomic measures or technologies, such as variable rate nitrogen applicators. Similarly, if policy is shifting towards rewarding public goods creation (Helm, 2017) then payment mechanisms may incentivise the machinery for collecting environmental data for basing payment rates.

A further issue is the lack of consolidation between manufacturer's systems for allowing progressive adoption of PAT bundles. Hence, a potential role for Government is to promote standardisation of systems through legal infrastructure and R&D support. It could, therefore, be further argued that the role of the Government is to provide a balance to industry promotion of these technologies, by offering demonstration, support for training and, if these benefits are economically or environmentally justified (e.g. to meet GHG reduction targets), potential subsidization for smaller farmers to engage in precision agricultural technologies on farm.

We find differences in attitudes towards the technology. Non-

[2] RTK (Real Time Kinematic) is the use of fixed position base stations to enhance the accuracy of GPS systems by transmitting signals that correct positioning errors caused by the Earth's atmosphere.

adopters with no intention of adopting perceive PAT to have too long a payback, adopters not wishing to invest further are more uncertain of the outcomes. Evaluation of the true economic benefits and return to investment is complicated by the application in diverse contexts. Castle et al. (2016) and Schimmelpfennig (2016) find that economic returns are dependent on farm related factors and vary due to the technology itself, the farm size and whether regular labour are currently employed on the land. There may be a further case for provision of regional field trials, demonstrating technologies in these diverse contexts. This approach may provide more assurances of the performance of the technology within localised circumstances or, conversely, serve to dissuade farmers as limitations emerge.

The qualitative analysis shows a diversity of responses, both positive and negative, to the technologies. One clear point of dissonance is the lack of a belief that the technology is somehow superior to a farmer's own knowledge for a number of non-adopting farmers. This reflects some of the arguments forwarded by Tsouvalis et al. (2000) towards 'yield mapping' which they saw as an example of 'technology push' and not developed in sympathy for the farmer needs. They argued for more co-creation of technologies and this would seem to be a pertinent avenue for future research studies.

On the margins of qualitative statements more intriguing reasons emerge for non-adoption, in that it is seen as a challenge to the ecological principles of some farmers. This latter reason potentially highlights the issues of farming identity. Other pathways such as agroecology or integrated farm management could run counter to the use of PAT which has so far been aligned with intensifying systems. This may also create barriers to low-input or organic farmers who could benefit from adoption of PATs but are deterred by this technological approach. Indeed, more ecological farming solutions tend to 'break up' present fields, which provides the main argument towards the need for a precision approach. The literature is lacking in qualitative studies of uptake of precision agriculture and further work should examine the role of these cultural factors and how sophisticated technologies, such as PATs, may create barriers to future adoption.

In addition, we address sequential adoption through our approach of discriminating between 'threshold' and 'contingent' technologies. More detailed understanding of progressive adoption of PATs would require longitudinal data sets, such as USDA's Agricultural Resource Management Survey (Miller et al., 2017; Schimmelpfennig and Ebel, 2016). A similar publically available adoption database does not exist for European farming systems as far as we are aware, but this would prove valuable in developing metrics and understanding the progression of adoption highlighted here.

5. Conclusions

A range of financial and non-financial incentives would increase adoption of PATs. The main barriers to intended adoption focus on the high cost element of the initial investment, leading to longer payback periods and limiting returns due to the economic carrying capacity of the farm. Moreover, uncertainty towards the potential for improved profitability to recoup this investment creates a significant barrier towards further adoption.

For farmers not currently using PATs, adoption could be realised by providing technical support or training as farmers seem to view these incentives positively. For those farmers already using PATs, regulatory pushes appear to determine willingness to further adopt PATs, indicating higher awareness of the roles these technologies can play in meeting compliance with tighter environmental rules, or reflecting a capacity for addressing regulatory barriers. This extends wider than direct agricultural regulation to other regulatory and infrastructural frameworks, most pertinently technological interventions to overcome limits in rural broadband coverage and the supporting data analytical services.

Disclaimer

The views expressed in this document are purely those of the authors and may not in any circumstances be regarded as stating an official position of the European Commission.

Acknowledgements

This project was funded by the European Union Joint Research Centre in Seville project, "The contribution of Precision Agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU", (JRC/SVQ/2015/J.4/0018/OC). AB and VE also acknowledge the support of the Scottish Government, Edinburgh RESAS strategic research programme (RD 2.3.12) for resources to complete the paper. Data collection was carried out by Wageningen Research (NL), SRUC (UK), ILVO (BE), AUA (GR) and Produkt und Markt (DE).

Appendix A. List and descriptors of technologies

1. Machine guidance systems. Guidance technologies are systems that pilot machinery using GPS. They enable farm machinery to follow straight lines to reduce overlaps and avoid gaps of the tractor and equipment passes.

2 Variable rate application – in particular variable rate nitrogen application

Variable rate application technologies (VRT) enable changes in the application rate to match actual need for fertiliser, lime, seeds, etc. in that precise location within the field. The basic idea is that, according to an electronic map or sensors, a control system calculates the input needs of the soil or plants and transfers the information to a controller, which delivers the input to the location.

3 Controlled Traffic Farming

Controlled Traffic Farming (CTF) is a system which confines all machinery loads to the least possible area of permanent traffic lanes. Current farming systems allow machines to run at random over the land, potentially causing compaction on a large part of the field. CTF can reduce tracking surface, and thus compaction, to just 15% of the field area. The permanent traffic lanes are normally parallel to each other. CTF allows optimised driving patterns and more efficient operations (i.e. reduced overlaps). As all operations are aligned, input applications can be targeted very precisely relative to the crop rows.

4 **Variable Rate Irrigation**

Variable rate irrigation (VRI) systems (also called precision irrigation systems) customise water application based on the crop's needs, derived from mapped topography information, soil data maps, prior yield data, and information about the crop's status. This can, for example, be achieved by pulsing sprinklers or boom sections on and off and/or controlling the system speed to modify the application depth along the length of the irrigator. VRI uses GPS technology and the control systems which can be easily retrofitted onto uniform sprinkler systems.

5 Variable Rate Pesticide Application

Variable rate pesticide application technologies enable changes in the application rate to match actual or potential pest stress in the field and avoid application to undesired areas of the field or plant canopies. They can also significantly reduce spray overlap. Current commercial applications focus on herbicide spraying.

One type of VR pesticide application adjusts the application rate based on a prescription map. Using the field position from a GPS receiver and a prescription map of desired rate, the input concentration is changed as the applicator moves through the field.

The other type of VR pesticide application is based on a real-time sensor, which controls the application rate based on the current situation of pest stress or canopy characteristics, without the generation of a prescription map. These systems involve either contact (e.g. mechanical) or non-contact (e.g. camera) sensing to identify either pests that need to be controlled or the crop and foliage/canopy that needs to be protected.

6 Variable Rate Seeding/Planting

Variable rate planters/seeders modify the rate of planting and seeding during application. This is often accomplished by disconnecting the planting/seeding system from the ground drive wheel, which normally keeps the planting/seeding rate constant when the speed of the tractor varies. By driving the planting/seeding system with an independent engine, gear box or hydraulic drive, the planting/seeding rate can be adjusted to the local soil potential. Besides being used for varying seed density, the technology of VRA seeding is also used to eliminate double planting in headlands and point rows.

The planting map is based on information like soil map, topography, irrigation, and long-term yield history. A GPS system and a seeder/planter equipped with a suitable control mechanism are also required for the system.

7 Precision Physical Weeding

Precision physical weeding technologies enable changes in the configuration of mechanical weeders or weed burners (e.g. in the position of or the resistance exerted by the tines of a harrow or the flow rate of the fuel) during weeding, to match weed presence and/or density in the field. The challenge of physical weeding is to obtain a high degree of selective weed control without producing considerable crop damage as a result of weeding. The technology is still in an experimental phase.

References

Aubert, B.A., Schroeder, A., Grimaudo, J., 2012. IT as enabler of sustainable farming: an empirical analysis of farmers' adoption decision of precision agriculture technology. Decis. Support Syst. 54, 510–520.

Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., van der Wal, T., Soto-Embodas, I., Gómez-Barbero, M., Barnes, A.P., Eory, V., 2017a. Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. Sustainability 9 (8), 1339.

Balafoutis, A.T., Koundouras, S., Anastasiou, E., Fountas, S., Arvanitis, K., 2017b. Life cycle assessment of two vineyards after the application of precision viticulture techniques: a case study. Sustainability 9.

Barnes, A.P., Willock, J., Toma, L., Hall, C., 2011. Utilising a farmer typology to understand farmer behaviour towards water quality management: nitrate Vulnerable Zones in Scotland. J. Environ. Plan. Manag. 54 (4), 477–482.

Barnes, A.P., Willock, J., Toma, L., 2013. Comparing a 'budge' to a 'nudge': farmer responses to voluntary and compulsory compliance in water quality management regimes. J. Rural Stud. 32, 448–459.

Barnes, A.P., Soto, I., Eory, V., Beck, B., Balafoutis, A., Sánchez, B., Vangeyte, J., Fountas, S.J., van der Wal, T., Gómez-Barbero, M., 2019. Exploring the adoption of precision agricultural technologies: a cross regional study of EU farmers. Land Use Policy 80, 163–174.

Beddington, J., Asaduzzaman, M., Clark, M., Ferna´ndez, A., Guillou, M., Jahn, M., Erda, L., Mamo, T., et al., 2012. Achieving Food Security in the Face of Climate Change: Final Report from the Commission on Sustainable Agriculture and Climate Change. Copenhagen: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS). www.ccafs.cgiar.org/commission.

Bogdanski, A., 2012. Integrated food-energy systems for climate-smart agriculture. Agric. Food Secur. 1, 9.

Burton, R.J.F., 2004. Seeing through the' good farmer's' eyes: towards developing an 572 understanding of the social symbolic value of' productionist' behaviour. Sociol. Ruralis 573 (2), 195–215 44.

Busse, M., Doernberg, A., Siebert, R., Kuntosch, A., Schwerdtner, W., Koenig, B., Bokelmann, W., 2014. Innovation mechanisms in German precision farming. Precis. Agric. 15, 403–426.

Castle, M.H., Lubben, B.D., Luck, J.D., 2016. Factors Influencing the Adoption of Precision Agriculture Technologies by Nebraska Producers. Presentations, Working Papers, and Gray Literature. Agricultural Economics, pp. 49. http://digitalcommons.unl.edu/ageconworkpap/49.

Chandra, A., McNamara, K.E., Dargusch, P., 2017. The relevance of political ecology perspectives for smallholder Climate-Smart Agriculture: a review. J. Polit. Ecol. 24, 821–842.

Crookston, K., 2006. A top 10 list of developments and issuesimpacting crop management and ecology during the past 50 years. Crop Sci. 46, 2253–2262.

Cullen, R., Forbes, S.L., Grout, R., 2013. Non-adoption of environmental innovations in wine growing. N. Z. J. Crop Hortic. Sci. 41, 41–48.

Eidt, C., Hickey, G., Curtis, M., 2012. Knowledge integration and the adoption of new agricultural technologies: Kenyan perspectives. Food Sec. 4, 355–367.

Eory, V., MacLeod, M., Topp, C.F.E., Rees, R.M., Webb, J., McVittie, A., Wall, E., Brothwick, F., Watson, C., Waterhouse, A., Wiltshire, J., Bell, H., Moran, D., Dewhurst, R.J., 2015. Review and update of the UK agriculture MACC to assess the abatement potential for the 5th carbon budget period and to 2050, the Committee on Climate Change.

Eurostat, 2015. Agriculture Main Tables. Available at:. http://ec.europa.eu/eurostat/web/agriculture/data/main-tables.

Faber, A., Hoppe, T., 2013. Co-constructing a sustainable built environment in the Netherlands—dynamics and opportunities in an environmental sectoral innovation system. Energy Policy 52, 628–638.

Feder, G., Just, R.E., Zilberman, D., 1985. Adoption of agricultural innovations in developing countries: a survey. Econ. Dev. Cult. Change 33, 255–297.

Fernandez-Cornejo, J., Daberkow, S., McBride, W., 2001. Decomposing the size effect on the adoption of innovations: agrobiotechnology and precision agriculture. AgBioForum 4 (2), 124–236.

Gebbers, R., Adamchuck, V.I., 2010. Precision agriculture and food security. Science 327 (5967), 828–831.

Gemtos, T.A., Markinos, A., Toulios, L., Pateras, D., Zerva, G., 2004. Precision farming applications in Cotton fields of Greece. CIGR International Conference 11–14 October 2004.

Gemtos, T.A., Fountas, S., Markinos, A., Aggelopoulou, A., Chatzinikos, A., 2006. Innovative Applications of Informatics in Agriculture and Rural Environment. Application and Perspectives of Precision Agriculture in Greece. Scientific papers of EPEGE, N. Greece, Thessaloniki, pp. 41–51.

Godwin, R.J., Richards, T.E., Wood, G.A., Welsh, J.P., Knight, S.M., 2003. An economic analysis of the potential for precision farming in UK cereal production. Biosyst. Eng. 84, 533–545.

Griffin, T.W., Lowenberg-Deboer, J., 2005. Worldwide adoption and profitability of precision agriculture. Imp. Brazil. Revista de Politica Agricola 4, 20–37.

Guest, G., MacQueen, K.M., Namey, E.E., 2012. Applied Thematic Analysis Thousand Oaks. SAGE Publications Ltd., CA.

Guillem, E.E., Barnes, A.P., 2013. Farmers perceptions of bird conservation and farming management at a catchment level. Land Use Policy 31, 565–575.

Helm, D., 2017. Agriculture after brexit. Oxford Rev. Econ. Policy 33, S124–S133.

Isgin, T., Bilgic, A., Forster, D.L., Batte, M.T., 2008. Using count data models to determine the factors affecting farmers' quantity decisions of precision farming technology adoption. Comput. Electron. Agric. 62, 231–242.

Kerry, R., Ingram, B.R., Navarro, F., Ortiz, B.V., Scully, B.T., 2017. Determining Corn Aflatoxin Risk Within Counties in Southern Georgia Using Remotely Sensed Data. ECPA, USA 2017 Proceedings.

Khanna, M., 2001. Sequential adoption of site-specific technologies and its implications for nitrogen productivity: a double selectivity model. Am. J. Agric. Econ. 83, 35–51.

Kutner, M.H., Nachtsheim, C.J., Neter, J., 2004. Applied Linear Regression Models, 4th ed. McGraw-Hill Irwin.

Lambert, D.M., Paudel, K.P., Larson, J.A., 2015. Bundled adoption of precision agriculture technologies by cotton producers. J. Agric. Resour. Econ. 40 (2), 325–345.

Lawson, L.G., Pedersen, S.M., Sorensen, C.G., Pesonen, L., Fountas, S., Werner, A., Oudshoorn, F.W., Herold, L., Chatzinikos, T., Kirketerp, I.M., Blackmore, S., 2011. A four nation survey of farm information management and advanced farming systems: a descriptive analysis of survey responses. Comput. Electron. Agric. 77 (1), 7–20.

Markinos, Ath, Toulios, L., Pateras, D., Zerva, G., Gemtos, T.A., 2003. A precision farming application in cotton in the small farms of Greece. Poster in the 4th European Conference on Precision Agriculture 489–490 16-18 June 2003.

Miller, N.J., Griffin, T.W., Bergtold, J., Ciampitti, I.A., Sharda, A., 2017. Farmers' adoption path of precision agriculture technology. Adv. Anim. Biosci. 8 (2), 708–712.

Montalvo, C., 2008. General wisdom concerning the factors affecting the adoption of cleaner technologies: a survey 1990–2007. J. Clean. Prod. 16, S7–S13.

Monteny, G.J., 2001. The EU nitrates directive: a european approach to combat water pollution from agriculture. Sci. World 1, 927–935.

Olsen, K., Elisabeth, P., 2003. An economic assessment of the whole farm impact of precision agriculture. Preoceedings of the 6th Internation Conference on Precision Agriculture and Other Precision Resources Management, Minneapolis MN, USA 14-17 July 2002 1803–1813.

Paxton, K.A., Mishra, A.K., Chintawar, S., Roberts, R.K., Larson, J.A., English, B.C., Lambert, D.M., Marra, M.C., Larkin, S.L., Reeves, J.M., Martin, S.W., 2011. Intensity of precision agriculture technology adoption by cotton producers. Agric. Resour. Econ. Rev. 40, 1–10.

Robertson, M., Isbister, B., Maling, I., Oliver, Y., Wong, M., Adams, M., Bowden, B., Tozer, P., 2007. Opportunities and constraints for managing within-field spatial variability in Western Australian grain production. Field Crops Res. 104, 60–67.

Robertson, M., Carberry, P., Brennan, L., 2009. Economic benefits of variable rate technology: case studies from Australian grain farms. Crop Past. Sci. 60, 799–807.

Robertson, M.J., Llewellyn, R.S., Mandel, R., Lawes, R., Bramley, R.G.V., Swift, L., et al., 2012. Adoption of variable rate fertiliser application in the Australian grains industry: status, issues and prospects. Precis. Agric. 13 (2), 181–199.

Rogers, E.M., 2003. The Diffusion of Innovations, 5th edition. Free Press, New York.

Schimmelpfennig, D., 2016. Farm Profits and Adoption of Precision Agriculture. U.S. Department of Agriculture, Economic Research Service Report 217. October 2016. .

Schimmelpfennig, D., Ebel, R., 2016. Sequential adoption and cost savings from precision agriculture. J. Agric. Resour. Econ. 41 (1), 97–115.

Schrijver, R., Poppe, K., Daheim, C., 2016. Precision Agriculture and the Future of Farming in Europe. Scientific Foresight Study IP/G/STOA/FWC/2013-1/Lot 7/SC5. European Parliamentary Research Service, European Union, Brussels December 2016.

Siebert, R., Toogood, M., Knierim, A., 2006. Factors affecting european farmers' participation in biodiversity policies. Sociol. Ruralis 46 318-240.

Silva, C.B., Dias de Moraes, M.A.F., Molin, J.P., 2011. Adoption and use of precision agriculture technologies in the sugarcane industry of São Paulo state, Brazil. Precis. Agric. 12, 67–81.

Smith, C.M., Dhuyvetter, K.C., Kastens, T.L., Kastens, D.L., Smith, L.M., 2013. Economics

of precision agricultural technologies across the Great Plains. Journal of the ASFMRA p185–p206.
Stafford, J., 2000. Implementing precision agriculture in the 21st century. J. Agric. Eng. Res. 76 (3), 267–275.
Sylvester-Bradley, R., Kindred, D.R., Marchant, B., Rudolph, S., Roques, A., Calatayud, S., Clarke, Gillingham, V., 2017. Agronomics: transforming crop science through digital technologies. Advances in Animal Biosciences: Precision Agriculture (ECPA) 2017 8 (2), 728–733 (2017).
Telabpour, B., Türker, U., Yegül, U., 2015. The role of precision agriculture in the promotion of food security. Int. J. Agric. Food Res. 4 (1), 1–23.
Tilman, D., Balzer, C., Hill, J., Befort, B.L., 2011. Global food demand and the sustainable intensification of agriculture. Proc. Natl. Acad. Sci. 108 (50), 20260–20264.
Tsouvalis, J., Seymour, S., Watkins, C., 2000. Exploring knowledge-cultures: precision farming, yield mapping, and the expert–farmer interface. Environ. Plann. A Econ. Space 32, 909–924.
van der Wal, T., Vullings, L.A.E., Zaneveld-Reijnders, J., Bink, R.J., 2017. Doorontwikkeling Van De Precisielandbouw in Nederland (No. 2820. Wageningen Environmental Research.
Zarco-Tejada, P., Hubbard, N., Loudjani, P., 2014. Precision agriculture: an opportunity for EU farmers – potential support with the CAP 2014-2020. Joint Research Centre (JRC) of the European Commission. Monitoring Agriculture ResourceS (MARS) Unit H04.
Zhang, C., Kovacs, J.M., 2012. The application of small unmanned aerial systems for precision agriculture: a review. Precis. Agric. 13 (6), 693–712.